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CALIBRATION OF PLATINUM RESISTANCE THERMOMETERS

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Calibration of Platinum Resistance Thermometers

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ABSTRACT

Results of five years experience in calibrating about 1000 commercial platinum resistance thermometers (PRT) are reported. These PRT were relatively small, and rugged, with ice-point resistances from 200 to 5000 ohms. Calibrations normalized in terms of resistance-difference ratios (Cragoe Z function) were found to be remarkably uniform for five of six different types of PRT tested and to agree very closely with normalized calibrations of the primary reference standard type PRT.

The Z function normalization cancels residual resistances which are not temperature dependent and simplifies interpolation between calibration points when the quality of a given type of PRT has been established in terms of uniform values of the Z function. Measurements at five or six well spaced base point temperatures with Z interpolation will suffice to calibrate a PRT accurately from 4 to 900 K. For most of the six types of PRT included in this report, four base-point measurements plus Z interpolation produced calibrations within the following limits of error: ±0.10 K from 4 to 20 K, ±0.02 K from 20 to 77 K, and ±0.05 K from 77 to 273 K.

INTRODUCTION

The calibration of a platinum resistance thermometer (PRT) involves relating the resistance of the thermometer to a function of temperature. It is desirable to define this temperature function with as few, and as convenient calibration points as possible. Also, if all PRT have the same temperature-resistance function the tasks of calibration, instrument standardization, and data reduction are simplified.

In 1962 Corruccini[1] demonstrated that accurate calibrations from 10 to 273 K for primary standard reference PRT can be accomplished with measurements at only two temperatures. The basis for his procedure involved the use of ratios of resistance difference, called Cragoe's Z function. Interpolation between two base point measurements was obtained from the relation

$$Z_T = (R_T - R_{T1}) / (R_{T2} - R_{T1}), \quad T1 < T < T2 \tag{1}$$

where R_{T1} and R_{T2} are resistance values at base point temperatures T1 and T2. The Z_T function simply expresses the fraction of the resistance span R_{T1} to R_{T2} which is realized in going from T1 to T. The Z function normalizes resistance-temperature relation for PRT and cancels residual resistances which are not temperature dependent.

When Corruccini compared Z_T function values based on T1 = 20 K and T2 = 90 K, for 35 primary reference standard PRT, all values (converted to equivalent temperature) were within 0.016 K, and the average of maximum errors did not exceed 0.005 K within the temperature interval 20 to 90 K.

The investigation reported herein determined that accuracies approaching those of primary reference standard PRT are obtainable using Z function interpolation for five types of relatively small, high resistance, low cost commercial PRT. To accomplish these results, Z_T values were obtained from multi-point calibrations of samples of six types of PRT purchased by Lewis Research Center since 1965.

Multi-point calibrations from 4 to 230 K were obtained using Lewis built cryostats. Coolants used for these cryostat tests were helium and nitrogen. Calibrations from 230 to 530 K were obtained in a controlled oil bath. Base point temperatures T1 and T2 were obtained in freely vented baths of liquid helium, hydrogen, and nitrogen as well as the ice, steam, and 530 K points which were obtained from oil bath calibrations. All calibrations were made by comparison with thermometers which had been calibrated by the NBS. Resistances were measured by potential ratio comparison with stable, accurate reference resistors. A complete description of the apparatus and operational procedure is given in a previous publication.[2]

DESCRIPTION OF THERMOMETERS

Figure 1 and Table I describe the PRT discussed in this report. The PRT manufacturer and model number identification listed in Table I does not imply recommendation or endorsement by NASA, nor does it imply that they are necessarily the best available thermometers. The thermometers are identified to help describe the type of PRT tested.

The PRT are divided into six types of field application PRT and two primary reference standard PRT (A and B). Type A are the same type as reported by Corruccini.[1] We have found that type B are comparable to type A in performance and are more rugged. Type A have a fragile glass-wire seal, which failed in three of seven PRT even though precautions were taken in handling.

PRT types 1 through 4 have the same type of platinum winding and are open ended so that the fluid can circulate internally as well as externally to improve response. Type 2 differs from type 1 only in resistance value. Types 3 and 4 have an end boss which enables them to be easily installed into a standard 3/16 inch (4.8 mm) outside diameter tube for probe applications, or to be soldered directly into a mounting hole in the test rig. Type 3B has a protection guard surrounding the platinum element for more rugged field applications. The resistance of type 4 is 1/5 of that of type 3, and consequently the platinum element is shorter. Types 1-4 constitute about 800 of the PRT reported herein.

Types 5 and 6 are surface mountable PRT, and 100 each have been purchased. Type 5 are enclosed in ceramic while type 6 are a more rugged type with a full metal enclosure.

PRT REFERENCE TABLE

Reference values of the Z function for any range of temperature from 4 to 900 K can be obtained from Eq. (1), using R_T values from Table II. The table lists relative values of resistance of PRT based on a value of 1000.00 at the ice-point (273.15 K). It has been used as the reference upon which to base the performance of the field application PRT reported herein. It is also used as the basis for PRT data reduction at Lewis.

The values given in Table II are average values and were obtained over three temperature segments, each in a different manner, that is:

4 - 20 K; Samples of PRT of types 3 and 4 were calibrated against a pair of NBS calibrated germanium resistance thermometers.

20 - 273 K; Derived from NBS calibrations of seven PRT of type A.

273 - 900 K; Computed using the Callender equation.

The temperature scales are the NBS Provisional - 1965 from 4 to 14 K and the IPTS - 1968 from 14 to 900 K. The probable error in the tabular values in terms of temperature is ± 0.03 K for 4 - 20 K, ± 0.005 K for 20 - 273 K, and ± 0.01 K for 273 - 900 K.

In Table II temperature increments are 1 K up to 100 K, and 10 K from 100 to 900 K. The table can be expanded by curve fitting to include smaller temperature increments especially in the non-linear range (below 60 K).

Table increments should be small enough that linear interpolation between listed values will not introduce significant errors. The basic Lewis reference table has temperature increments of 0.1 K up to 80 K and 1.0 K from 80 to 900 K.

Based on the hypothesis that values of the Z function for a field application PRT are essentially the same as the values for a standard PRT,

$$Z_X = \left(\frac{R_T - R_{T1}}{R_{T2} - R_{T1}}\right)_X \simeq \left(\frac{R_T - R_{T1}}{R_{T2} - R_{T1}}\right)_S = Z_S, \tag{2}$$

tables of resistance vs temperature for individual field PRT can be computed readily using a rearrangement of Eq. (1) with two calibration points T1 and T2, and data taken from Table II.

$$R_{T,X} = R_{T1,X} + \left[(R_T - R_{T1}) / (R_{T2} - R_{T1})\right]_S (R_{T2} - R_{T1})_X, \tag{3}$$

where:

X = PRT being calibrated

S = Values from Table II

And T1 and T2 are the same temperatures for both the test PRT being calibrated and the values obtained from Table II.

RESULTS

Table III summarizes the Z function correspondence for each PRT type. Shown are the ranges of deviations (expressed in terms of temperature) of measured Z_X values from the reference Z_S values obtained from Table II. The deviations are obtained from

$$\Delta T_Z = (Z_X - Z_S) / (\Delta Z/\Delta T). \tag{4}$$

The values listed in Table III represent maximum values of multiple point calibrations (about 10 points per PRT), and, hence, are limits of error. The ΔT_Z values for types A and B were obtained using NBS calibration data. These values, ± 0.005 K from 20.2 to 77.4 K and ± 0.01 K from 77.4 thru 273.15 K, should be considered the best obtainable using a two point Z function interpolation procedure. These deviation errors are negligible compared to accuracy requirements for most field measurements.

Table III lists ΔT_Z data for the temperature interval 20.2 to 77.4 K for PRT types 3A and 3B, from different tests listed in chronological order. The results for temperature interval 20.2 to 77.4 K shown for PRT types 1, 2, and the first listing of 3A should not be considered as representative of these PRT, because temperature gradients apparently existed in the cryostat during these calibrations. The Z function correspondence for these PRT is undoubtedly better. This is verified for type 3A by the lesser ranges of ΔT_Z, -0.01 to 0.003 K and -0.01 to 0.00 K, obtained in later calibrations for the same temperature interval. Also the scatter of the data for the earlier tests was higher than the known PRT repeatability and the resistance measurement accuracy of the tests. This experience indicates that unless extreme care is taken during multi-point calibrations, temperature gradient errors in the cryostat may be larger than the PRT deviation from the standard Z function. For PRT types 1, 2, 3A, 3B, 4, and 6, more accurate calibrations were probably obtained from two point calibrations and interpolation than from multi-point calibrations. Limits of error for these five types were probably within ±0.10 K from 4 to 20 K, ±0.02 K from 20 to 77 K, and ±0.05 K from 77 to 273 K.

Notice that the ΔT_Z results for type 5 and one buy of type 3 (3B') were considerably higher than for the other PRT. This shows that some types of PRT have Z function values that do not agree closely with values obtained from Table II. Therefore a statistical sample of each type of PRT must first be multi-point calibrated to determine their suitability for Z function interpolation.

Table IV shows the deviations ΔT_Z Eq. (4) that can be expected when interpolating or extrapolating to the listed temperature T3 for the different base-point calibrations. Most of the examples presented in Table IV are for greater values of (T2-T1) than presented in Table III. Along with the range of deviation at temperature T3, Table IV also gives the average deviation $\overline{\Delta T_X}$ as well as the standard deviation σ_X. The table was obtained from point calibrations at the six temperatures listed. Not all combinations of base-point temperatures, T1 and T2, and check-point temperature T3 are given in the table. Comparing Table IV to Table III it can be seen that the wider the temperature span between the base points, the greater the deviation of interpolated values (examples 1, 2, 3, 4, 7 in Table IV). Also, when T3 is obtained by extrapolation well beyond the base-point temperature, the deviations may be large (examples 5, 6).

Hence, base-point calibration temperatures should be close enough to the field application temperatures to insure adequate accuracy when interpolating

CONCLUDING REMARKS

This paper has presented the results of calibrating about 1000 commercial platinum resistance thermometers (PRT) at the NASA Lewis Research Center. These PRT were of six different types, all relatively small and rugged, with ice-point resistances from 200 to 5000 ohms. PRT of five of the six types proved to have uniform resistance-difference ratios (Cragoe Z function) which agreed closely with those of the primary reference standard type PRT. Therefore, for most of our field applications, in which required accuracies are within ±0.1 K, two base-point measurements together with Z interpolations are sufficient providing the base-point temperatures are close enough together. To cover the 4 to 273 K range, base points at about 4, 20, 77, and 273 K are used.

To enable reference values of the Z function to be determined for interpolations, a resistance-temperature reference table for primary quality platinum was used. This table was developed from NBS calibration data for seven primary reference standard PRT from 20 to 530 K. The basic data were extended down to 4 K from calibrations of PRT against germanium resistance thermometers which had been calibrated by the NBS.

The Z function provides a convenient means of solving two problems associated with PRT. First, it normalizes calibrations in terms of nondimensional resistance-difference ratios. Second, it cancels out residual resistance which is not a function of temperature. However, it should be emphasized that interpolations by values of the Z function as derived from the reference table are justified only when multi-point calibrations of statistical samples of a given type of PRT have established conformance with the reference table.

Most of the six types of PRT tested at NASA-Lewis were calibrated with four base-point measurements and Z interpolations within these limits of error: ±0.10 K from 4 to 20 K, ±0.02 K from 20 to 77 K, and ±0.05 K from 77 to 273 K. One type of PRT and one procurement of another type failed to meet the specifications for Z function uniformity and therefore could not be calibrated by this procedure within acceptable limits of error.

The concept of base-point measurements with interpolation by Z function has resulted in standardization procedures of calibration, instrumentation, and data processing. These procedures are described in a previous publication.[2]

REFERENCES

[1] R. J. Corruccini, "Interpolation of Platinum Resistance thermometers, 10° to 273.15° K", Temperature, Its Measurement and Control in Science and Industry (Reinhold Pub. N. Y. 1962), Vol. 3. Part I, pp. 329-338.

[2] D. H. Sinclair, H. G. Terbeek, and J. H. Malone, "Cryogenic Temperature Measurement Using Platinum Resistance Thermometers", NASA TN D-4499 (April 1968).

TABLE I. - LIST OF PLATINUM RESISTANCE THERMOMETERS

Group	Resistance at 273.15 K, R, Ω	Approximate cost $	Mfr.	Model number
A	25.5	450	a	8164
B	25.5	500	b	162 D
1	5000	200	b	146AN-4
2	1380	175	b	146BK-2
3A	1000	140	b	150KC
3B	1000	150	b	150KD
3B'	1000	100	c	1012-1
4	200	140	b	150-LC
5	1000	60	d	RT3000-1
6	200	150	b	118AEB

a=Leeds and Northrup

b=Rosemount Engineering Company

c=Thermal Systems, Inc.

d=Semco (Scientific Engineering and Manufacturing Company)

These identities are listed to help describe the types of thermometers discussed; they do not constitute an endorsement by NASA.

TABLE II – PLATINUM RESISTANCE-TEMPERATURE REFERENCE TABLE

TEMPERATURES IN K, IPTS-68 (NBS-65 BELOW 14 K)

TEMP., K	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
0					0.9138	0.9275	0.9573	0.9945	1.0455	1.1132
10	1.204	1.321	1.471	1.658	1.894	2.180	2.531	2.953	3.446	4.024
20	4.686	5.459	6.336	7.326	8.433	9.660	10.999	12.467	14.049	15.752
30	17.571	19.512	21.575	23.754	26.055	28.473	30.992	33.622	36.352	39.185
40	42.116	45.136	48.239	51.425	54.690	58.030	61.441	64.923	68.469	72.081
50	75.756	79.481	83.254	87.077	90.945	94.858	98.805	102.790	106.805	110.852
60	114.929	119.037	123.165	127.317	131.488	135.678	139.888	144.117	148.351	152.600
70	156.864	161.139	165.423	169.715	174.012	178.314	182.624	186.940	191.266	195.594
80	199.920	204.250	208.580	212.910	217.250	221.590	225.930	230.270	234.610	238.960
90	243.300	247.650	251.990	256.330	260.660	265.000	269.330	273.650	277.970	282.290

TEMP., K	0.0	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
100	286.61	329.64	372.38	414.80	456.93	498.81	540.46	581.88	623.11	664.18
200	705.08	745.83	786.43	826.90	867.22	907.42	947.50	987.45	1027.27	1066.98
300	1106.57	1146.03	1185.38	1224.60	1263.70	1302.69	1341.55	1380.29	1418.92	1457.43
400	1495.82	1534.09	1572.24	1610.28	1648.19	1686.00	1723.68	1761.25	1798.70	1836.03
500	1873.25	1910.36	1947.35	1984.22	2020.98	2057.62	2094.14	2130.55	2166.84	2203.01
600	2239.07	2275.01	2310.84	2346.55	2382.14	2417.62	2452.98	2488.22	2523.35	2558.36
700	2593.26	2628.03	2662.69	2697.23	2731.65	2765.95	2800.13	2834.20	2868.14	2901.97
800	2935.68	2969.26	3002.73	3036.07	3069.30	3102.40	3135.38	3168.24	3200.98	3233.59

TABLE III. - DEVIATIONS OF Z FUNCTION, IN TERMS OF TEMPERATURE, FROM REFERENCE VALUES FOR TEMPERATURE INTERVALS T1 TO T2

	T1 = 4.2 K; T2 = 20.2 K		T1 = 20.2 K; T2 = 77.4 K		T1 = 77.4 K; T2 = 273.15 K	
PRT type	Number of samples, N	Range of deviations, ΔT_Z, K	Number of samples, N	Range of deviations, ΔT_Z, K	Number of samples, N	Range of deviations, ΔT_Z, K
A			7	-0.005 to 0.005	2	-0.01 to 0.01
B			2	-0.005 to 0.005	1	-0.01 to 0.01
1	5	-0.10 to 0.15	7	-0.01 to 0.02		
2			5	-0.03 to 0.02		
3A	2	-0.05 to 0.00	4	-0.005 to 0.04	5	0.00 to 0.04
			4	-0.01 to 0.003		
			2	-0.01 to 0.00		
3B	3	0.00 to 0.06	3	-0.013 to 0.01	5	0.00 to 0.04
			4	-0.014 to 0.01		
			3	-0.004 to 0.00		
3B'			17	-0.02 to 0.07		
4	2	-0.07 to 0.03	2	-0.02 to 0.004	2	0.00 to 0.05
5			7	0.00 to 0.32		
6			4	-0.02 to 0.01		

TABLE IV: - INTERPOLATION AND EXTRAPOLATION DEVIATIONS AT TEMPERATURE T3 FROM POINT CALIBRATIONS AT T1 AND T2

Example	Temperature, K			PRT type	Number of samples, N	Range of deviations, ΔT_Z, K	Average deviation, $\overline{\Delta T_Z}$, K	Standard deviation, σ_X, K
	T1	T2	T3					
1	4.2	77.4	20.2	3	22	-0.027 to 0.064	0.022	0.020
2	4.2	273.15	20.2	3	22	0.006 to 0.098	0.054	0.022
3	4.2	273.15	77.4	3	45	0.027 to 0.087	0.063	0.010
4	20.2	273.15	77.4	3	22	0.039 to 0.086	0.066	0.009
				4	12	0.050 to 0.080	0.065	0.010
5	77.4	273.15	20.2	3	22	-0.278 to -0.611	-0.468	0.061
				4	12	-0.358 to -0.567	-0.458	0.070
6	77.4	273.15	373.15	3	45	0.031 to -0.677	-0.132	0.154
				4	99	-0.075 to -0.418	-0.139	0.048
7	77.4	530.0	273.15	3	45	0.010 to 0.248	0.105	0.045
				4	99	0.087 to 0.341	0.153	0.040

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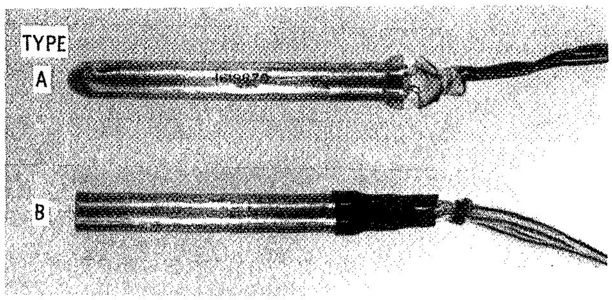
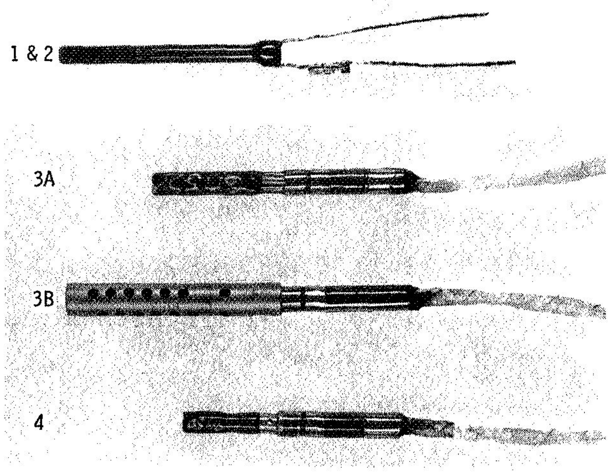
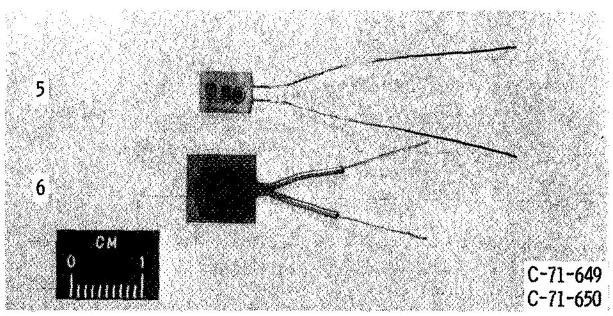


PLATINUM STANDARDS



PROBE MOUNTING



SURFACE MOUNTING

Figure 1. - Platinum resistance thermometers.